CONSTRUCTION FEATURES OF THE WATER WORKS OF THE GREATER WINNIPEG WATER DISTRICT[1]

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The idea of obtaining a pure and practically unlimited supply of water from a visible source not only appealed to the citizens of Winnipeg but also to those of the surrounding municipalities, so that in 1913 the Manitoba Legislature passed an act incorporating the Greater Winnipeg Water District, comprising the cities of Winnipeg and St. Boniface, the town of Transcona, the municipality of St. Vital, and parts of the municipalities of Fort Garry, Assiniboia and Kildonan. The powers and functions of the Corporation are discharged by an Administration Board, consisting of the mayors and reeves of the cities and municipalities, together with four aldermen from Winnipeg, and an alderman from St. Boniface; the mayor of Winnipeg is the chairman of this Board. In accordance with the provisions of the act, the active management of the District has been put into the hands of two commissioners.

Prior to the act of legislature forming the District, the council of the city of Winnipeg appointed a board of consulting engineers to report on the feasibility and cost of a water supply from Shoal Lake, Ontario. This board, Rudolph Hering, Frederic P. Stearns and James H. Fuertes, submitted its report in 1913, recommending Shoal Lake as a source of supply. Briefly summarized, the conclusions and recommendations of the report were as follows:

1. Shoal Lake, without help from the main Lake of the Woods, can be depended upon to furnish, even in the driest years, a large part, if not all, of the water needed for Winnipeg until the population reaches about 850,000; and, with the help of the Lake of the Woods, it can furnish a practically inexhaustible supply.

[1] Read before the Montreal Convention, June 23, 1920. Discussion is invited and should be sent to the Editor. This paper supplements that by James H. Fuertes on the principles of design of the same works, published in the Journal of September, 1920, page 693.

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2. The water of Shoal Lake is of excellent quality for domestic and manufacturing purposes, being soft, practically free from contamination, without noticeable color, free from odors, and of an agreeable taste.

3. The best point to take the water is from the west end of Indian Bay, an arm of Shoal Lake, as the depth of the water and the configurations of the bottom and shores in this neighborhood are favorable.

4. In order to avoid the dark-colored water discharged by Falcon River, and cut off the shallow flowage at the extreme westerly end of Indian Bay, a dyke across the end of the bay and a canal leading therefrom to Snowshoe Bay should be constructed, through which to divert the undesirable waters.

5. The best way to get Shoal Lake water to Winnipeg is to bring it down first through a concrete aqueduct 85 miles in length, laid with a continuous down-grade to a point about a mile east of Transcona, and then through a 5-foot steel pipe to the Red River. A 5-foot cast-iron pipe, in tunnel, is recommended to convey the water under the river, and thence a 4-foot cast-iron pipe, laid in the city streets, to the Winnipeg reservoirs at McPhillips Street.

6. The concrete portion of the aqueduct should be given a capacity of 85,000,000 imperial gallons per day, but the pipe line portion should be given the smaller sizes above stated, capable of discharging 25,000,000 gallons per day by gravity into McPhillips Street reservoirs.

7. It is recommended that the water be taken out of Shoal Lake by gravity rather than by pumping it over the summit in pipe lines.

8. The total cost to the Greater Winnipeg Water District of building the intake, Falcon River Diversion Works, concrete aqueduct and steel and cast-iron pipe lines, including crossings of streams and rivers, waste weirs and other appurtenant works, will be $13,045,600. This estimate does not include the cost of acquiring land, or of branch pipes to the different communities; neither does it include any allowance for water damages, nor for interest charges.

9. It is recommended as a part of the plan, but not for immediate construction, that a new storage reservoir, holding about 250,000,000 gallons and estimated to cost between $300,000 and $400,000, be built at a point about a mile east of Transcona, and that a main pumping station be established to force the water to the city through

the 5-foot steel pipe, and through branches to be laid to the different sections of the city and district requiring the water. This reservoir and pumping station should be completed and ready for use before the demands for water reach the gravity capacity of the steel pipe line.

Final location of route. The organization of the Water District being completed, the work was immediately undertaken and was actively pushed in an effort to complete it within the time limit laid down in the original report of the consulting engineers, with the double object of gaining the use of the new supply as early as possible with its benefits to the individual and of minimizing the capital charges for interest during the construction period. During the winter of 1913–14 the route for the easterly 85 miles of the aqueduct was finally located, five survey parties being engaged from October 17 until March 1. The method followed in general was a system of surface profiles on surveyed road allowances running north and south with occasional profiles on east and west lines. The information so accumulated was completed, contour lines were developed, and the line was projected on a plan, following, as nearly as possible, the principle of a westward slope when it could be obtained, as for instance, along the valley of the Birch River which was followed for 15 miles. Trial lines were then run in the field and cost estimates were computed in the usual way. The line finally chosen was but 8 per cent longer than an air line between the intake and the reservoir site and 35 per cent of it is practically on the average slope, that is, the most economical. During this study there were run 362 miles of transit lines, 1317 miles of level lines, 96 miles of precise levels fixing bench marks for reference from point to point, 380 square miles of topography and 2½ miles of earth soundings. The average gradient is 0.62 feet per 1,000 feet; the lightest gradient, 0.11 feet per 1,000 feet; the heaviest gradient, 1.55 feet per 1,000 feet.

Preparatory works. During the season of 1914 there were undertaken and completed the following works: An earth-filled dyke 1½ miles long, built in about 14 feet of water for the purpose of excluding from the intake waters the discharge of the swamp-fed Falcon River, whose color was very dark; a standard-gauge railway with 102 miles of trackage upon the right-of-way chosen for the aqueduct; and a telephone line of No. 14 copper on wooden poles.

Falcon dyke. The Falcon River dyke is a structure designed purely as a guiding wall to divert the flow of the Falcon River across the westerly end of Indian Bay into an adjoining body of water, Snowshoe Bay, through a canal across the neck of land separating these two bays. The material for it was obtained from a suitable deposit of sand located a few hundred feet north of the north end of the dyke. It was excavated with steam shovel and delivered by means of dinky and 4-yard cars into place. The building of a trestle was avoided by the use of a scow held out from the advancing end of the dyke with heavy stringer timbers upon which the railway track was extended; the full cars were backed up over these stringers, were dumped at the end of the dyke and the empties were run out on to the scow until the train had been discharged. This method was continued until the southerly shore was reached, when the scow was removed and a light shallow trestle of short length permitted the closure of the dyke against the shore. The easterly exposed face of the dyke was heavily rip-rapped with rock from a borrow pit located at the north end of the structure. A light course of rip-rap and planting of willows will protect the westerly face of the dyke.

The effectiveness of this dyke in permitting the bleaching of the waters of the Bay was early in evidence, the color of the water dropping from 150 to 15 and to 10 before the dyke was completed. The color of the waters in Shoal Lake is lighter than that of the waters of the Lake of the Woods, with which Shoal Lake is connected, and for the reason which may be seen at a glance from the study of the following table:

Drainage area of Lake of the Woods, square miles	27,000
Surface area of Lake of the Woods	1,250
Ratio of drainage area to surface area	21.6
Drainage area of Shoal Lake, square miles	360
Surface area of Shoal Lake, square miles	107
Ratio of drainage area to surface area	3.5

It is evident that the waters of Shoal Lake are exposed to the bleaching action of sun and winds for a much longer time than are those of the Lake of the Woods.

Railway. No great difficulty attended the construction of a railway, although most of the route was swamp-covered and surface drainage was a first essential, the country being so flat. The grade

was built up from side borrow entirely, and for several miles this borrow consisted of nothing more than peat, particularly on the summit of land separating Lake of the Woods from the Lake Winnipeg drainage. Gravel pits were found at convenient intervals and the work of ballasting was about 80 per cent completed at the close of the season.

The construction of this railway was a sine qua non of the successful building of the aqueduct. The country traversed was virgin land between miles 40 and 96 and nearly altogether swamp covered. No highways were available for the transport of material for construction nor could any be built cheaply; railway transport was recognized immediately as the key to rapid construction of the aqueduct.[3]

The railway has also been recognized as an essential of maintenance of the water supply and it has behooved the management of the Water District, since they must operate the railway, to encourage the development of the natural resources along the route. These are fortunately numerous, consisting of large deposits of sand, gravel, a fine quality of granite, large quantities of wood fuel, and the land when drained and stripped of growth is a very fertile and productive soil; the settlement of this land is being encouraged and it is not at all unlikely that at an early date the railway as such may be considered a self-supporting entity.

The telephone system was in many sections built twice, as it was almost impossible to distribute the necessary poles; the wire which had been transported on men's backs was first strung on convenient tree stumps until the completion of the railway permitted the erection of a proper telephone structure.

Right-of-way. The right-of-way chosen was generally 300 feet in width from the reservoir site near Transcona at Mile 13 to Mile 74; thence to Mile 84, the Birch River forms one boundary; and thence eastward to the intake the general width chosen was 500 feet, chiefly because the maximum depth of cut necessary for the crossing of the height of land was in the neighborhood of 23 feet and the material to be excavated consisted of 7 feet of peat, 10 to 15 feet of sand and

[3] The magnitude of the construction work is indicated by the following approximate figures of the more important quantities: Earth excavation and backfill, 7,500,000 cubic yards; rock excavation, 16,000 cubic yards; concrete, 455,000 cubic yards; reinforcing steel, 10,000 tons; Portland cement, 575,000 barrels.

sandy clay to a waxy clay floor; that the accommodation afforded by so wide a right-of-way was warranted by the experiences of construction, for numerous slides occurred, spoil from which had to be thrown in places over 150 feet away from the trench.

District supplied concrete aggregate. To attain rapid construction, it was early determined that the work should be let in sections of moderate length; this policy also encouraged the engagement of local contracting organizations but it required the Water District itself to operate the system of transport and to excavate and supply the sand, gravel and crushed stone for the manufacture of concrete. Gravel pits of a satisfactory quality were not to be found convenient to each 18- or 20-mile stretch of the structure; and confusion would have been the result from any effort toward the sub-division of the responsibility either for the supply of material or for the transport of plant and material. The Water District therefore selected, after test, two satisfactory sources of sand and gravel supply and throughout the major portion of the time of construction the District supplied a mixture of sand and gravel concrete aggregate upon platforms opposite the contractors' working points. The policy of supplying mixed material not only minimized the quantity of rolling stock necessary for the work but also assured the use of a uniform material throughout the entire mileage of the aqueduct. The difficulties of inspection of concrete making and mixing were also greatly diminished thereby, and the cost to the contractors for the manufacture of concrete was necessarily less than would have been the case had sand and gravel or crushed stone been supplied separately.

In determining the quality of this uniform concrete aggregate, a series of laboratory tests was carried out during the winter of 1914–1915 in an effort to determine the mixture of Portland cement and of aggregate for the production of a concrete which would be watertight, sufficiently strong in compression and at the same time not wasteful of cement. These experiments were carried on with mixtures containing only one barrel of Portland cement per cubic yard of concrete and it was ultimately determined that by the use of a proper proportion of dust or fine sand in a fairly graded sand a 6-inch wall of concrete could be made impervious to water under pressure of 80 pounds per section inch, the test standard adopted. Recently investigators have been able to make 1-inch slabs impervious against similar pressure and by similar means. This subject was discussed in a paper read by D. L. McLean and the author before the Engineering Institute of Canada in 1915.

The Water District, having determined upon the policy of supplying the sand and gravel to the contractors, determined also to supply the necessary Portland cement under purchase contracts and thereby to ensure a uniform cement for the entire project. Such a supply was obtained in Winnipeg from the mills of the Canada Cement Company and by virtue of the local sources being available the supply was kept steady and deliveries were prompt as required. Storage of cement by the District was thus avoided.

The total traffic over the District railway during the period of construction was fairly heavy. Carloads of aggregate contained 23 cubic yards each or a total weight of 130,000 pounds per unit. The rate of consumption of concrete materials ran as high as 1200 cubic yards per day and the principal source of supply was located at Mile 31. Throughout the entire construction approximately 1,000,000 cubic yards of sand and gravel were moved for concrete manufacture, for building up trench foundation where firm soil was at too low an elevation, and for backfill where native and local materials were scarce. This traffic was in addition to the haulage of Portland cement, about 600,000 barrels, the distribution of contractor's plant and the transport of passengers. A tri-weekly mixed train served to distribute plant, cement and to meet the requirements of passenger movement; additional trains handled the sand and gravel.

Intake. The site chosen for the intake is a rock cut on the peninsula which forms the north end of the dyke above described. Gathering walls of rock fill over a sand core were extended about 200 feet into the lake to permit the draught of water from a sufficient depth. A concrete chamber located in the rock cut houses the trash racks, the screens, the sluice gates and stop logs which permit the control of waters discharged into the aqueduct.

During construction a cofferdam of sand across the opening between the gathering walls provided the shelter for the rock excavations. This type of cofferdam, easily protected, maintained and easily removed, was quite satisfactory.

Aqueduct construction. Speaking generally, each contractor endeavored to keep his work concentrated at each camp, and, except for backfilling operations, the excavation, trench trimming and aqueduct building were confined within a distance of one-half mile in each case. The number of camps per contract varied from two to five, depending upon the possible rates of construction. The

total number of camps during the successive years were: 1915, eleven camps; 1916, fourteen camps; 1917, twenty camps; 1918, twenty-two camps; besides those operated at the District's source of material supply, three in number. The maximum number of men engaged upon the project was about 2500.

Earth handling. The methods of handling earth varied considerably. On the easterly 47 miles Bucyrus draglines in capacities from $\frac{5}{8}$ to $3\frac{1}{2}$ cubic yards, were used for excavating and for backfilling. These draglines were specially designed to be self-propelling, and were supported upon the swamp surface by means of timber pads built in sections, the machine itself being mounted upon rollers.

TABLE 1

A few records of earth excavation from the trench with the various classes of machinery engaged

TYPE OF MACHINE	CAPACITY	AVERAGE DEPTH OF CUT		MATERIAL EXCAVATED	AVERAGE YARDAGE EXCAVATED PER 10 HOUR DAY
	cu. yd.	*ft.*	*ins.*		*cu. yd.*
Marion shovel.......	$1\frac{1}{2}$ (dipper)	12	0	Clay	612
Walking dredge.....	1 (dipper)	8	0	Clay	745
Bucyrus dragline....	1 (bucket)	6	0	3′ peat, 3′ sandy clay	640
Bucyrus dragline....	1 (bucket)	7	5	1′ top soil, 6′5″ fine sand (wet)	740
Bucyrus dragline....	1 (bucket)	9	0	2′ peat, 3′ fine sand, 4′ sand and gravel	900
Bucyrus dragline....	2 (bucket)	14	0	12′ peat, 2′ clay in bottom of trench	1950
Bucyrus dragline....	$3\frac{1}{2}$ (bucket)	18	5	6′ peat, 12.5′ clay	2920

Between Miles 31 and 51, a few steam shovels were used with greater or less success; these were supplemented by drag-lines. Between Miles 13 and 31, walking dredges, figure 1, were used; here the cut was generally shallow and the soil fairly firm. Each type of machine had its advantages but speaking generally the dragline seemed the most suitable device. Table 1 gives some records of their work.

Throughout the easterly 47 miles the spoil of excavation was dumped close to the trench and formed into an elevated grade for the dinky railway track used to distribute the mixed concrete. Earth so placed was convenient for backfilling but was occasionally the cause of slips of the trench wall, in which event the tramway

grade was maintained by means of pole trestles. Payment for the work of excavation was limited to fixed slopes of the trench walls, namely, one horizontal on three vertical in firm soil and one

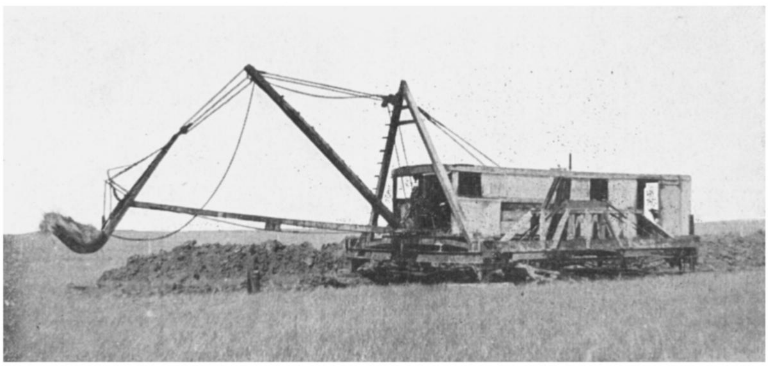

FIG. 1. WALKING DREDGE EXCAVATING TRENCH ON A PRAIRIE SECTION

FIG. 2. REPLACING WITH SAND AND GRAVEL THE MUSKEG MATERIAL WHERE FOUND BELOW THE GRADE LINE

horizontal on one vertical in soil which would not stand on steeper slopes. Machine excavation was permitted to within 6 inches of the determined floor grade, and it was required that the remainder of the earth should be removed by hand.

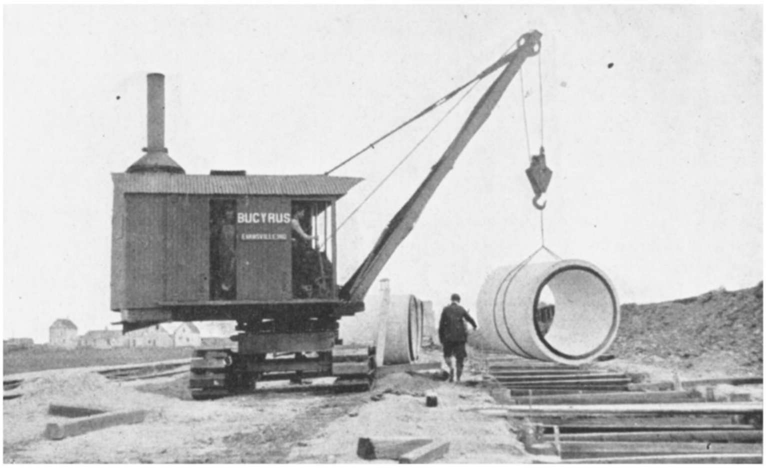

FIG. 3. LOWERING AN 8-FOOT LENGTH OF 66-INCH LOCK JOINT PIPE INTO THE TRENCH

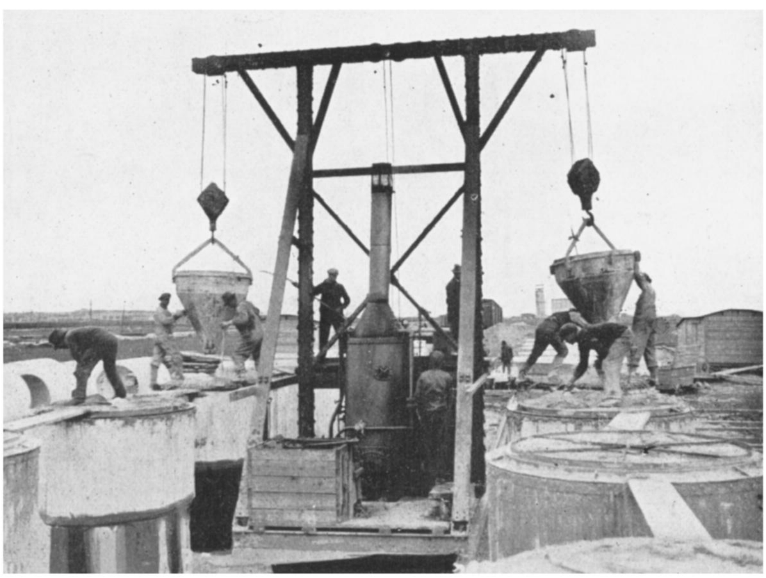

FIG. 4. GANTRY DELIVERING CONCRETE TO FORMS FOR 66-INCH PIPE, CAST IN 8-FOOT LENGTHS WITH 8-INCH WALLS

As all of the trench grade lay below the ground water level the problem of handling ground water seepage and trench floor seepage was constantly a prominent one. Notwithstanding this fact it was possible to obtain compliance with the requirements of the specifications that all concrete must be "laid in the dry." This was accomplished by means of a system of side-wall trench drains and of a centre line depressed drain lined with a wooden box with transverse cover slats, surrounded with coarse gravel or broken stone. Diaphragm pumps operated by gasoline were successful in maintaining the ground water below the grade of the trench floor. Trimming of the surface of the earth for the reception of concrete was not permitted until the hour of concrete placing, and by observance of this rule the preservation of a firm surface for the receipt of concrete was assured.

Foundations. The material encountered in this hundred miles of trench work varied all the way from peat to rock, including soupy clay, waxy clay, the various intermediate mixtures of clay and sand, sand dry or under water pressure and quicksand, granite and trap rock. By care in location, therefore, little rock excavation was necessary anywhere. Each class of soil found at invert grade presented a separate and distinct problem in the effort to obtain a highly resisting trench floor. Dryness was a prime essential and was generally obtained by the methods described.

Soupy clay was made firm by casting into it broken stone of varying sizes, mostly of the riprap dimension.

Quicksand was excavated below grade between lines of sheet piling, a layer of stone and gravel was superposed, and within this layer the box drain was maintained at its proper grade. This stone served to prevent the movement of the sand as the water escaped upward from the sand, and also provided a foundation satisfactory for the support of concrete maintained dry until set.

In rock cuts a floor of sand was generally placed, as the length of each cut was small.

Where the peat beds were found to extend to depths below the grade chosen for the invert of the aqueduct, the trench was widened and the peat was taken out to whatever depth it would extend, figure 2. Sand and gravel were then placed in the bottom of the trench under water, and after having built this bed to about 2 feet above invert grade it was underdrained and allowed to settle. The bed of sand was then trimmed in the ordinary way, and a strong foundation was thus provided.

In the case of flowing clay foundations, it became necessary to open the trench wider than for the standard structure, and in some cases to build piled foundations and use a heavily reinforced invert. Great care was necessary in backfilling in such trenches to prevent the transmission of pressures irregularly to the structure.

Along Snake Lake, which parallels the aqueduct route for 2 miles near the intake, and at certain other points, a porous foundation would have been the source of a serious trouble inasmuch as the surface waters would stand higher than the structure itself and the structure when empty would be liable to float. Generally along such locations the material available for backfill use was of a peaty nature and light in weight. The precaution was here taken of building a heavily weighed invert; the engineer's judgment was constantly at test as to whether a weighed invert should be considered necessary or not. With a structure 10 feet 9 inches wide inside, the expense of such an invert was very great and was avoided whereever the earth of the trench floor seemed fairly tight. In deciding upon the use of a weighted invert for this purpose, the following options were discarded for the reasons set out:

a. Imported backfill of earth; too expensive.

b. Increased overfill; of doubtful effectiveness and necessarily huge in quantity.

c. Weighted arch or superstructure; not very efficient and would require a very sturdy invert.

The success of the design chosen and the efficiency of the supervision maintained have been proved through the first year's operation, as the aqueduct through these locations is still secure in place, although frequently far from full of water and although it has been constantly wholly submerged.

Backfilling. The specifications required that between the walls of the trench and the aqueduct the earth backfill should be tamped carefully to a depth of 4 feet. This precaution was taken in conjunction with a moderately light design of arch, which arch, however, was quite safe against pressures of earth backfill even without packed earth at the haunches. In cuts wholly in muskeg, it was impossible to carry out such a specification. In a few cases, a slight addition to the thickness of the arch haunches was provided, but generally the only precaution taken was the deposition against each haunch of imported sand and gravel to the depth prescribed.

The backfill was then completed with a machine, generally the machine used by the contractors for the excavation of trench. It was piled to a depth of 4 feet upon the crown in the case of solid earth, or of 5 feet in the case of peaty material. The minimum width of backfill top prescribed was 8 feet, or where that was exceeded by the clear inside width of the aqueduct then that width became the governing dimension for the top of the backfill. The side slopes of backfill were one and three fourths horizontal on one vertical, a slope which proved to be satisfactory. The only modification made in these side slopes was along Snake Lake, where high waters of the lake would rise upon the face of the slope; here the slopes were made three horizontal on one vertical.

The backfill was grassed over with a selected mixture, very heavy sowing of seed assuring a thick bottom on moist soil and insuring a catch on the driest sections. Most of this seeding on the easterly 50 miles of work was done by contractors; but a considerable acreage of the westerly portion of the line has been seeded by Water District forces this year. The seeding operations included the removal and burning of stumps and other combustible rubbish, removal of stones, trimming and crowning of the backfill and the raking and rolling of the seed bed. The work done by the District was generally on firm material well settled during the two or three years which had elapsed since the building of the backfill. This backfill was thoroughly stirred up with specially designed harrows built to hold themselves on the summit of the dump. No rolling was done but the seed was well buried, a shelter crop of grain being planted at the same time.

Concrete making. Throughout the work of aqueduct construction, control of the mixture of sand and gravel was maintained by the District's engineers through careful inspection and direction of the operation of the District's own gravel pit where the excavation, screening and re-mixing of the sand and gravel were carried on, producing a uniform concrete aggregate with the desired proportions of sand and dust. It must be remembered the prime objective in the manufacture of concrete for this conduit was water-tightness with economy in the consumption of Portland cement. This material when dry weighed about 122 to 125 pounds per cubic foot or with 4 per cent moisture, a common condition, 110 to 112 pounds per cubic feet. About 29 cubic feet of aggregate was sufficient to build one cubic yard of concrete in place, allowing for all waste both of aggregate and of concrete. The average consumption of Port-

land cement was $1\frac{1}{4}$ barrels per cubic yard for all work in the 100,000,000-gallon section of the water supply scheme, the easterly 85 miles. The consumption of Portland cement in the pressure pipe of the Red River Valley siphon was about 2 barrels per cubic yard in a mixture averaging about one bag of cement, $1\frac{1}{2}$ cubic feet of sand and $2\frac{1}{2}$ cubic feet of gravel not over $1\frac{1}{4}$ inches in diameter.

Generally speaking, the invert of the aqueduct was laid in pads of 15 feet length, alternate pads being first laid and when these were hardened the closures being placed. The process of invert making included the placing, tamping and screeding and the floating and trowelling of the surface exposed to water flow. The shoulder was built to a level plane at the chosen elevation, its inner margin being about 1 inch within the wall of the arch at its foot. This practice afforded a clean and definite line of intersection between the inner surfaces of the arch and the invert. Into the green concrete of the shoulder a thin wooden strip was placed and bound by the setting concrete. After the concrete had set and before it became hard, this shoulder was brushed with wire brushes removing all laitance and exposing the pebbles of the concrete.

The arch was commonly built within 45-foot forms, each set of forms being arranged for transport up and down the trench upon a suitable carriage. The bulkheads were designed to support and to secure the beaded copper strip water-stop. As the trench was commonly in shallow cut, it was necessary to mix the concrete with some slight excess of water although the presence of the fine sand in the aggregate gave a considerable fluidity to the mixture. It was therefore necessary to work the concrete carefully into place in the form and, after filling the form, to keep adding concrete, at the same time working the material off the surface of the crown of the inner form until the material became too stiff for further working. After the first season of construction, it was found that this precaution ensured the building of an arch structure without longitudinal crown cracks, a common distressing difficulty in all arch building especially where the crown is thin and the arch form flat or of large radius.

River crossings. The conduit crosses the Falcon River close to the discharge of that stream into Indian Bay, and about 4,000 feet west of the intake. It crosses the Birch River three times at Miles 82, 78 and 74, the Whitemouth River at Mile $64\frac{1}{2}$, the Brokenhead River at Mile 41, the Seine River at Mile 4, and the Red River at

Mile 3. Crossings of the Falcon, Birch, Whitemouth and Brokenhead Rivers are inverted siphons of reinforced concrete built in the trench and designed with a loss in head conformable to the average loss in head for the same distance in the horseshoe structures between which it is interpolated. A Venturi meter is built in place with the Falcon River siphon, the superstructure or register chamber being frost-proofed with earth covering in the shape of a huge truncated cone. At the first and third Birch River crossings and at the Whitemouth and Brokenhead crossings, an overflow was provided combined with provision for cutting off the flow in the structure. Ingress and egress for small boats is provided at each river crossing. A weir built in the side of the conduit at each of these regulating points, as also at Mile 17, is of sufficient length to permit the discharge of the entire capacity of the aqueduct with but small rise in head. It is frost-protected by discharging into the bottom of a well from the lip of which the water is discharged through a culvert into the river, or in the case of Mile 17, into an 11-mile overflow ditch.

The Seine River lies within the Red River Valley and is parallel to the Red River at the point of crossing by the conduit. The Red River Valley inverted siphon begins at Mile 17 and discharges into the reservoir of the city of Winnipeg on the west side of the Red River 2½ miles from the city. Four miles west of the east end of this siphon is located a site for a future 250,000,000-gallon reservoir, as the land surface there is at a convenient elevation for the building of an earth contained basin, and to this point the capacity of the siphon is 100,000,000 gallons per day. The westerly twelve miles of the siphon has a capacity of 60,000,000 gallons per day by aid of a booster pump at the Red River margin or of 32,000,000 gallons per day by gravity. Ultimately a second line of similar capacity from the Water District reservoir to the centers of distribution in the Water District will be laid to care for the maximum daily demand. Local reservoirs within the Water District will provide the balance between the maximum daily demand and the maximum hourly demand.

The easterly four miles of this Red River Valley siphon is a 96-inch diameter reinforced concrete pipe with 8-inch wall, trench-built in 15-foot sections and in the standard two portions, namely, invert first and superstructure following. The transverse joints were ultimately calked with a V of neat cement hammered into

place. The backfill over this 96-inch pipe and over the other circular pressure pipe at easterly river crossings is 6 feet in depth, it being more important to prevent frost forming within the pressure pipe whose perimeter is entirely wetted than within the horseshoe section whose crown is never wetted.

Between the Red River margin and the site chosen for the Water District's reservoir at Mile 13 the conduit is a 66-inch diameter lock-joint reinforced concrete pipe with 8-inch wall, manufactured at a central point and in 8-foot lengths, transported to the trench on railway cars and laid and jointed in the trench, the jointing not being done until the pipe had been covered to a depth of one foot with earth and had obtained a uniform temperature.

This trench was very interesting. The contract provided for vertical payment lines and the contractors decided that for convenience in operations those payment lines must also be the construction lines. The first operation was to drive 20-foot round wooden piles along each side of the trench and at intervals of 2½ to 4 feet. These piles afforded support for the steam shovel with which the earth was removed from the trench and also ensured that the berm of the trench should be firm and capable of supporting the machine with which the heavy pipes were lowered into the trench. The entire process of excavating, pipe laying and preliminary backfilling was confined within a distance of less than 500 feet as a rule. Backfilling to a depth of one foot above the pipe followed immediately after the laying of the pipe to line and grade and the building of supporting haunches of plain concrete alongside the pipe. The trench wall piling was then withdrawn and the piles were carried forward for second use.

This Red River Valley siphon passes through a soil bed whose sea-deposited clay is heavily impregnated with sulphates of sodium, of magnesium and calcium and bearing occasionally some other salts. To prevent reaction of these salts in ground waters upon the reinforced concrete pipe, this trench, from Mile 13 to the Red River, and its extension through the city of Winnipeg from the Red River to the city reservoirs, was thoroughly underdrained. An 8-inch vitrified tile was laid with open joints along the lower corner of the trench and, after the shoulders or haunches of the concrete had been built alongside the pipe in place, a backfilling of coarse gravel was placed nearly to the top of the shoulder, ensuring the collection of water from the trench walls and its delivery to the drain tile.

No serious difficulty attended the construction of this ten miles of lock-joint pipe line. At places such as in the crossing under the Seine River bed, at railway track crossings, and where the earth banks showed a tendency to slip, the wall piling was left in place, along with a small quantity of shoring.

Similar methods of construction were applied to the 48-inch diameter reinforced concrete lock joint pipe line with $6\frac{1}{2}$-inch wall laid from the west shaft of the Red River tunnel to the City of Winnipeg reservoir on Logan Avenue, a distance of 2.3 miles. This pipe was manufactured in 10-foot lengths.

All the lock-joint pipe was manufactured in a yard at Transcona, one mile north of the line of work but convenient to railway tracks for the receipt of reinforcing steel and of cement. This yard was laid out as a double-ended plant and the two longitudinal halves of the yard were duplicates in most particulars. Eight Little Wonder concrete mixers served the yard and permitted the manufacture of an average of about thirty lengths of 66-inch pipe per day. The reinforcing mesh, delivered in 46-inch widths and incidentally the heaviest mesh ever manufactured, was bent to shape in special rolls located on one side of the middle of each end of the yard. The square twisted steel bars used in manufacturing the interior cage of reinforcement were bent to shape and assembled in cages on the opposite point of the yards. The pipes were cast within steel forms set up upon a double line of concrete bases reaching from end to end of the yard. Provision was made for the admission of steam to and about these forms. After the pouring had been completed, steam was furnished from a boiler plant located in the middle of the yard.

The mixed concrete was transported from the mixers at the ends of the yard to the forms by means of a specially designed travelling derrick or crane, figure 3, whose outrigger arms supported conical concrete buckets which discharged through a plug valve in the bottom of the bucket on to a circular disk set upon the inner form of the pipe. The pipe was cast spigot end upward, a special form being provided for the formation of the spigot and for the support of the copper water stop during the process of pouring.

Storage of the pipe after steam curing was provided along each side of the yard, the pipe being laid upon its side upon transverse runways. It was loaded for shipment upon cars spotted on tracks lining the outer edges of the storage yard.

Red River tunnel crossing. The Red River is crossed with cast iron pipe 60 inches in diameter, set within vertical shafts lined with concrete, and within a concrete-lined horizontal rock tunnel 10 feet square. Complete valve control is provided at each end. On the easterly end a reinforced concrete circular surge tank with concentric receiving tank was built, the whole being housed in for frost protection within a masonry shell. The construction of this work afforded very few difficulties. One notable feature, however, was the method adopted by the contractors for the support of the walls of the excavation for the receipt of the surge tank. The floor was about 20 feet below the surface of the ground. This support consisted of a sixteen-sided timber mitered framing without shoring, dressed with vertical sheeting. This arrangement gave clear access to the whole of the interior and was a perfectly safe protection for the 50-foot diameter excavation. The well structure is supported on concrete piers sunk to rock.

The shaft lining, of 2-foot reinforced concrete circular wall, was shod with heavy steel plate and was built in sections as the lining was sunk by excavation from within. It proved easy to maintain this 16-foot shaft in a vertical position on center.

The cast iron pipe lining of the tunnel proper was designed in 8-foot lengths with a special interior calked joint. Calking was done with lead wool.

The backfilling of concrete around the pipe in the tunnel was done through tremies consisting of 4-inch well holes sunk from the surface of the ground or through the bed of the river as the case might be. A 150-foot length of tunnel was refilled at each stage, concrete being built up to within about 1 foot of the roof of the tunnel excavation, and the remainder of the cavity being filled with mortar. The mortar was poured continuously down one tremie until it rose to at least river level in the other tremies entering the section. This ensured the sealing of the tunnel solidly under heavy pressure.

Concrete in alkali soil. This is a subject of vast importance to the municipalities and other owners of concrete structures throughout central Canada and central United States. The injurious elements found in the soils are the sulphates of metals, viz., magnesium, sodium and calcium, and these sulphates in the presence of ground water attack the concrete from the outside transforming it into a sulphate of calcium, destroying its cohesion and ultimately wrecking the structures. Unfortunately this is proved from the experience of the cities of Winnipeg and St. Boniface with concrete sewers; of

building owners with respect to foundations in Saskatoon, Moose Jaw, Winnipeg and other cities; and of owners of irrigation projects who are losing their canal linings, their controlling works and their concrete siphons or pressure pipes.

The engineers of the Water District after 1916 took the precaution of providing underdrainage for the trench carrying the pressure pipes of the Red River Valley inverted siphon, as about that time it became evident that it is very doubtful whether Portland cement concrete of any consistency, strength or density, porosity or permeability is safe against the attack of these ground-water solutions of sulphate salts. A portion of the 100,000,000-gallon structure, between Miles 13 and 17, a 96-inch diameter concrete pipe with 8-inch wall is now found to be suffering decay on its surface from

TABLE 2

Meters on the Winnipeg Aqueduct

METER	PIPE DIAMETER	THROAT DIAMETER	MEASURING
	inches	*inches*	
1	108	42	Draft from lake
2	96	37	Delivery to main reservoir
3	66	29	Draft from main reservoir
4	24	16	Delivery to St. Boniface.
5	36	20	Delivery to Winnipeg at Red River high pressure pumping station
6	48	28	Delivery to Winnipeg at terminal reservoir on Logan Avenue
7	12	Empire Compound	Delivery to Transcona at reservoir
8	8	Compound	Delivery to Fort Garry via City of Winnipeg mains

these agencies, and the Water District is engaged in a program of sub-soil drainage parallel to the conduit and reasonably close to it in the hope that this drainage, by lowering the ground water plane between the two parallel drainage trenches, will cause the action to cease.

Fortunately, the soils which contain these salts extend over a small area of the country crossed by this important water supply project and a system of ground water tests is being established so that the risk can be continually observed and necessary precautions can be taken from time to time.

Meters. There are eight meters on the aqueduct, located as shown in table 2, by which the distribution of the water is checked constantly.